PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

Date of mailing (day/month/year) 28 May 2001 (28.05.01)	
International application No. PCT/AU00/01115	**Applicant's or agent's file reference** FP12950
International filing date (day/month/year) 14 September 2000 (14.09.00)	**Priority date** (day/month/year) 14 September 1999 (14.09.99)
Applicant XU, Wei et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

22 March 2001 (22.03.01)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Claudio Borton Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION CONCERNING SUBMISSION OR TRANSMITTAL OF PRIORITY DOCUMENT

(PCT Administrative Instructions, Section 411)

To:

GRIFFITH HACK
GPO Box 4164
Sydney, NSW 2001
AUSTRALIE

Date of mailing (day/month/year) 02 July 2001 (02.07.01)	
Applicant's or agent's file reference FP12950	**IMPORTANT NOTIFICATION**
International application No. PCT/AU00/01115	International filing date (day/month/year) 14 September 2000 (14.09.00)
International publication date (day/month/year) 22 March 2001 (22.03.01)	Priority date (day/month/year) 14 September 1999 (14.09.99)
Applicant THE UNIVERSITY OF SYDNEY et al	

1. The applicant is hereby notified of the date of receipt (except where the letters "NR" appear in the right-hand column) by the International Bureau of the priority document(s) relating to the earlier application(s) indicated below. Unless otherwise indicated by an asterisk appearing next to a date of receipt, or by the letters "NR", in the right-hand column, the priority document concerned was submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b).

2. This updates and replaces any previously issued notification concerning submission or transmittal of priority documents.

3. An **asterisk(*)** appearing next to a date of receipt, in the right-hand column, denotes a priority document submitted or transmitted to the International Bureau but not in compliance with Rule 17.1(a) or (b). In such a case, **the attention of the applicant is directed** to Rule 17.1(c) which provides that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity, upon entry into the national phase, to furnish the priority document within a time limit which is reasonable under the circumstances.

4. The **letters "NR"** appearing in the right-hand column denote a priority document which was not received by the International Bureau or which the applicant did not request the receiving Office to prepare and transmit to the International Bureau, as provided by Rule 17.1(a) or (b), respectively. In such a case, **the attention of the applicant is directed** to Rule 17.1(c) which provides that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity, upon entry into the national phase, to furnish the priority document within a time limit which is reasonable under the circumstances.

Priority date	Priority application No.	Country or regional Office or PCT receiving Office	Date of receipt of priority document
14 Sept 1999 (14.09.99)	PQ 2811	AU	13 June 2001 (13.06.01)

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No. (41-22) 740.14.35	Authorized officer Eugénia Santos (Fax 338.87.40) Telephone No. (41-22) 338.83.38

U 013870-6

PATENT COOPERATION TREATY

From the:
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:	**PCT** NOTIFICATION OF TRANSMITTAL OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT (PCT Rule 71.1)
GRIFFITH HACK GPO Box 4164 SYDNEY NSW 2001	Date of mailing *day/month/year* 11 SEP 2001
Applicant's or agent's file reference AJM:MG:FP12950	**IMPORTANT NOTIFICATION**

International Application No.	International Filing Date	Priority Date
PCT/AU00/01115	14 September 2000	14 September 1999

Applicant
THE UNIVERSITY OF SYDNEY et al

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translations to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices)(Article 39(1))(see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide

Name and mailing address of the IPEA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	MICHAEL HALL Telephone No. (02) 6283 2474

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PATENT COOPERATION TREA

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference AJM:MG:FP12950	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. **PCT/AU00/01115**	International Filing Date *(day/month/year)* 14 September 2000	Priority Date *(day/month/year)* 14 September 1999

International Patent Classification (IPC) or national classification and IPC

Int. Cl. 7 G02F 1/035, 1/383

Applicant

THE UNIVERSITY OF SYDNEY et al

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

   [X] This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 4 sheet(s).

3. This report contains indications relating to the following items:

I	[X]	Basis of the report
II	[ ]	Priority
III	[ ]	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
IV	[ ]	Lack of unity of invention
V	[X]	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
VI	[ ]	Certain documents cited
VII	[X]	Certain defects in the international application
VIII	[ ]	Certain observations on the international application

Date of submission of the demand 22 March 2001	Date of completion of the report 7 September 2001
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer **MICHAEL HALL** Telephone No. (02) 6283 2474

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/AU00/01115

I. Basis of the report

1. With regard to the **elements** of the international application:*
   - [ ] the international application as originally filed.
   - [X] the description, pages **1, 4-7,** as originally filed,
     pages , filed with the demand,
     pages **2-3,** received on **23 August 2001** with the letter of **23 August 2001**
   - [X] the claims, pages , as originally filed,
     pages , as amended (together with any statement) under Article 19,
     pages , filed with the demand,
     pages **8-9,** received on **23 August 2001** with the letter of **23 August 2001**
   - [X] the drawings, pages **1-3,** as originally filed,
     pages , filed with the demand,
     pages , received on with the letter of
   - [ ] the sequence listing part of the description:
     pages , as originally filed
     pages , filed with the demand
     pages , received on with the letter of

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
   These elements were available or furnished to this Authority in the following language which is:
   - [ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).
   - [ ] the language of publication of the international application (under Rule 48.3(b)).
   - [ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:
   - [ ] contained in the international application in written form.
   - [ ] filed together with the international application in computer readable form.
   - [ ] furnished subsequently to this Authority in written form.
   - [ ] furnished subsequently to this Authority in computer readable form.
   - [ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - [ ] The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

4. [ ] The amendments have resulted in the cancellation of:
   - [ ] the description, pages
   - [ ] the claims, Nos.
   - [ ] the drawings, sheets/fig.

5. [ ] This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report*

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

A method of thermally poling a silica based waveguide (12) comprises exposing a region of the waveguide (12) to an electric field (for example, via capillary electrodes (22, 24) inserted into holes in the waveguide); directing a laser beam (18) into the region exposed to the electric field to effect localised heating of the region via direct absorption; and scanning the laser beam (18) over the region at a rate selected to avoid heating of the region above the glass transition temperature. Reversing the electric field while scanning the laser beam (18) allows the formation of periodic poled gratings. The waveguide (12) can comprise an optical fibre.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	**1-14**	**YES**
	Claims		**NO**
Inventive step (IS)	Claims	**1-14**	**YES**
	Claims		**NO**
Industrial applicability (IA)	Claims	**1-14**	**YES**
	Claims		**NO**

2. Citations and explanations (Rule 70.7)

Citation

D1 : Y. Quiquempois et al., Optical Materials **9** (1998) 361-367

NOVELTY (N) AND INVENTIVE STEP (IS)

D1 represents the closest prior art, and teaches thermally poling an optical fibre by applying an electric field to conductors inserted in the fibre, and exposing the region to be poled to a CO_2-laser beam to effect localised heating of the region between room temperature and 800 degrees Celsius. In an embodiment D1 teaches heating a 4mm length of fibre to 400 degrees Celsius for one hour (page 366, column 1).

However, D1 does not disclose or suggest scanning the laser beam over the region, as per the claims. Since this appears to lead to significantly improved poling properties (eg, 0.06 pm/V at page 366 column 1 of D1, compared to 0.29 pm/V at page 5 of the instant application), in significantly shorter times (eg, 1 hour at page 366 column 1 of D1, compared to 55 seconds at page 7 of the instant application), the claims are considered to be novel and inventive over D1.

INDUSTRIAL APPLICABILITY (IA)

The subject matter of the claims is applicable to the industrial manufacture of poled optical waveguide devices.

VII. Certain defects in the international applicati n

The following defects in the form or contents of the international application have been noted:

Claims 13 and 14 rely on reference to the drawings, and hence do not comply with PCT Rule 6.2(a).

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ATENT COOPERATION TREAT

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference FP12950	**FOR FURTHER ACTION**	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
International application No. **PCT/AU00/01115**	International filing date *(day/month/year)* 14 September 2000	(Earliest) Priority Date *(day/month/year)* 14 September 1999
Applicant THE UNIVERSITY OF SYDNEY et al.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 5 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

[ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing:

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readable form.

[ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (See Box II).

4. With regard to the **title**,

[ ] the text is approved as submitted by the applicant.

[X] the text has been established by this Authority to read as follows:

LASER ASSISTED THERMAL POLING OF SILICA BASED WAVEGUIDES

5. With regard to the **abstract**,

[ ] the text is approved as submitted by the applicant

[X] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. **1**

[X] as suggested by the applicant.

[ ] because the applicant failed to suggest a figure

[ ] because this figure better characterizes the invention

[ ] None of the figures

INTERNA AL SEARCH REPORT

International application No.
PCT/AU00/01115

A.	**CLASSIFICATION OF SUBJECT MATTER**
Int. Cl. [7]:	G02F 1/035, 1/383
According to International Patent Classification (IPC) or to both national classification and IPC	
B.	**FIELDS SEARCHED**
Minimum documentation searched (classification system followed by classification symbols)	
IPC: G02B, G02F	
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched	
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)	
DWPI, JAPIO, INSPEC	

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	Optics Letters, Vol 25, 15 February 2000 (Optical Society of America), "Carbon dioxide laser-assisted poling of silicate-based optical fibers ", P. Blazkiewicz et al., pp 200-202. Whole document	1-14
X Y	Optical Materials, Vol. 9, January 1998 (Elsevier Science B.V.), "Study of organized $\chi^{(2)}$ susceptibility in germanosilicate optical fibers", Y. Quiquempois et al., pp. 361-367. Sections 1-2, 4	1, 7-14 2-6

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 8 November 2000	Date of mailing of the international search report 15 NOV 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer **MICHAEL HALL** Telephone No : (02) 6283 2474

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	WO 96/16344 A (UNIVERSITY OF SYDNEY) 30 May 1996	
Y	Page 6 lines 29-31, pages 9-10	2-6
A	Whole document	1, 7-14
	US 5856880 A (FARINA ET AL.) 5 January 1999	
Y	Column 2 line 28 to column 3 line 8, column 12 lines 37-63	2-6
A	Whole document	1, 7-14

INTERNA AL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/01115

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	9616344	AU	38646/95	CA	2206018	EP	792473
		US	5966233				
US	5856880	NONE					

END OF ANNEX

PCT/AU00/01115
Received 23 August 2001
10/049334
JC13 Rec'd PCT/PTO 11 FEB 2002

the deposition of the electrodes. Furthermore, as the sign of the EO coefficient can only be changed by applying a poling voltage of different polarity, this is practically impossible with such a poling system, since at the high voltages required, shortening between adjacent electrodes would occur.

Summary of the invention

A first aspect of the present invention provides a method of thermally poling a silica-based waveguide, comprising the steps of:

- exposing a region of the waveguide to an electric field;

- directing a laser beam into the region which is exposed to the electric field;

- irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- scanning the laser beam over the region.

The method may further comprise scanning the laser beam across the region to effect poling of the region.

The method may comprise varying the power density of the laser beam while scanning. Accordingly, a method of non-uniform thermal poling can be provided.

A direction of the electric field may be changed as the laser beam is scanned over the region. Accordingly, it can be possible to alternate the sign of the EO coefficient in non-uniform thermal poling.

Where the material comprises glass, the laser beam is preferably an infrared (IR) laser, for example a CO_2 laser.

Where the material is an optical fibre, wires may be inserted into tubular holes extending substantially parallel to a core of the optical fibre located between the tubular holes, and a differential voltage may be applied to

the wires to create the electric field. The core of the optical fibre may comprise a germanosilicate material co-doped with phosphorous.

A second aspect of the present invention provides an apparatus for thermally poling a silica-based waveguide, comprising:

- a means for exposing a region of the waveguide to an electric field;

- a means for directing a laser beam into the region which is exposed to the electric field;

- a means for irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- a means for scanning the laser beam over the region.

A third aspect of the present invention provides an optical device incorporating a silica-based waveguide when thermally poled by the above-described method.

Preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 shows a schematic drawing of an experimental set-up embodying the present invention.

Figure 2 shows a plot illustrating positive poling as a function of time embodying the present invention.

Figure 3 shows a plot illustrating negative poling as a function of time embodying the present invention.

Detailed Description of the Preferred Embodiments

In Figure 1, a Mach-Zehnder interferometer 10 was used for in situ measurement of the evolution of the EO coefficient in an optical fibre 12. The optical fibre 12 is a twin hole fibre with a germano silicate core codoped

The claims defining the invention are:

1. A method of thermally poling a silica-based waveguide, comprising the steps of:

- exposing a region of the waveguide to an electric field;
- directing a laser beam into the region which is exposed to the electric field;
- irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and
- scanning the laser beam over the region.

2. A method as claimed in claim 1 wherein the laser is controlled to such that the power density of the laser beam is varied while scanning.

3. A method as claimed in any one of the preceding claims wherein a direction of the electric field is changed as the laser beam is scanned over the region.

4. A method as claimed in claim 3, wherein the direction of the electric field is reversed as the laser beam is scanned over the region.

5. A method as claimed in any one of the preceding claims wherein the electric field and/or laser are controlled to effect a non-uniformly poled structure in the region.

6. A method as claimed in claim 5 wherein the electric field and/or laser are controlled to effect a periodic poled structre.

7. A method as claimed in any one of the preceding claims wherein the laser beam is an IR laser beam.

8. A method as claimed in any one of the preceding claims when applied to a waveguide in the form of an optical fibre.

9. A method as claimed in claim 8, wherein wires are inserted into tubular holes extending substantially parallel to a core of the optical fibre located between the

tubular holes, and a differential voltage is applied to the wires to create the electric field.

10. A method as claimed in either claim 8 or claim 9, when applied to an optical fibre in which the core comprises germanosilicate co-doped with phosphorous.

11. An apparatus for thermally poling a silica-based waveguide, comprising:

- a means for exposing a region of the waveguide to an electric field;

- a means for directing a laser beam into the region which is exposed to the electric field;

- a means for irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- a means for scanning the laser beam over the region.

12. An optical device incorporating a silica-based waveguide when thermally poled by the method as claimed in any one of claims 1 to 11.

13. A method of thermally poling a silica-based waveguide substantially as herein described with reference to the accompanying drawings.

14. An apparatus for thermally poling a silica-based waveguide substantially as herein described with reference to the accompanying drawings.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 March 2001 (22.03.2001)

PCT

(10) International Publication Number
WO 01/20389 A1

(51) International Patent Classification[7]: G02F 1/035, 1/383

(21) International Application Number: PCT/AU00/01115

(22) International Filing Date: 14 September 2000 (14.09.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PQ 2811 14 September 1999 (14.09.1999) AU

(71) Applicant *(for all designated States except US)*: THE UNIVERSITY OF SYDNEY [AU/AU]; Parramatta Road, Sydney, NSW 2006 (AU).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: XU, Wei [CN/AU]; Unit 5, 34 Talara Road, Gymea, NSW 2227 (AU). WONG, Danny [AU/AU]; 15 Sanders Road, Baulkham Hills, NSW 2153 (AU). TOWN, Graham [AU/AU]; 5 Victoria Street, Erskineville, NSW 2043 (AU). CANNING, John [AU/AU]; 10 Francis Street, Carlton, NSW 2218 (AU). BLAZKIEWICZ, Paul [AU/AU]; 8 Araluen Avenue, Moorebank, NSW 2170 (AU).

(74) Agent: GRIFFITH HACK; GPO Box 4164, Sydney, NSW 2001 (AU).

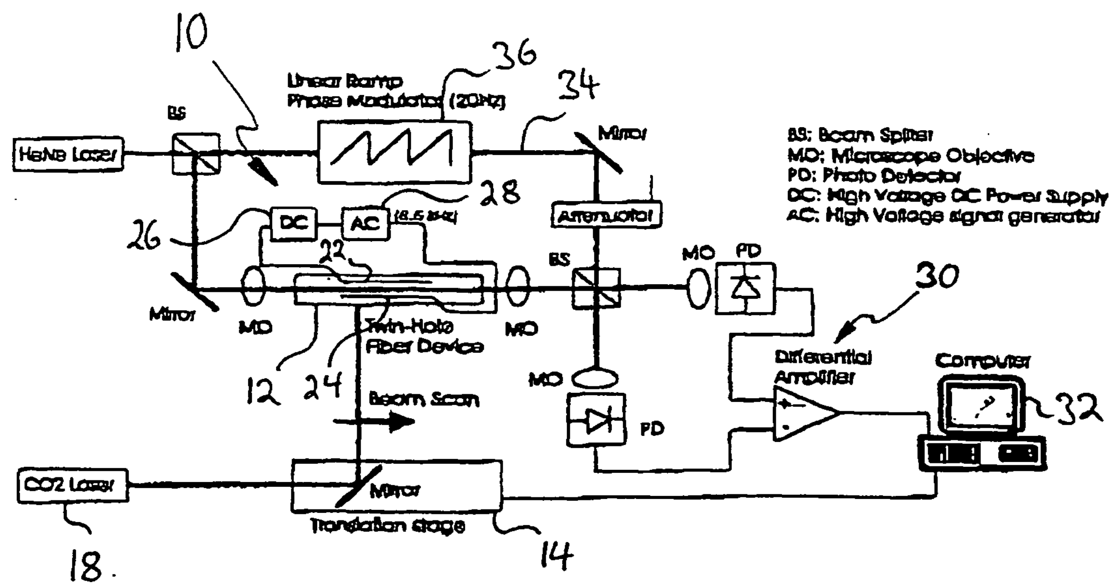
(81) Designated States *(national)*: AU, CA, JP, KR, US.

(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: LASER ASSISTED THERMAL POLING OF SILICA BASED WAVEGUIDES



(57) Abstract: A method of thermally poling a silica based waveguide (12) comprises exposing a region of the waveguide (12) to an electric field (for example, via capillary electrodes (22, 24) inserted into holes in the waveguide); directing a laser beam (18) into the region exposed to the electric field to effect localised heating of the region via direct absorption; and scanning the laser beam (18) over the region at a rate selected to avoid heating of the region above the glass transition temperature. Reversing the electric field while scanning the laser beam (18) allows the formation of periodic poled gratings. The waveguide (12) can comprise an optical fibre.

WO 01/20389 A1

LASER ASSISTED THERMAL POLING OF SILICA BASED WAVEGUIDES

Field of the invention

The present invention relates broadly to a method and apparatus for thermal poling of materials and to devices incorporating poled materials.

Background of the invention

The induced variation of the electro-optic (EO) coefficient of materials (hereinafter referred to as poling) has been attempted e.g. for optical fibres and bulk glass to produce a residual EO coefficient chi(2) in the glass material.

Two main methods are presently applied for poling optical fibres or bulk glass: (I) thermal poling and (II) ultraviolet (UV) poling. The latter is believed to effect poling through non-thermal effects caused by UV absorption in the glass.

In both methods, a high poling voltage is applied across the material during either the heating process or the UV absorption to produce the EO coefficient changes.

The largest values of the EO coefficient in glass have been produced by UV poling. However, the resulting EO variations have been difficult to reproduce and the underlying principles are not fully understood, which makes this method unsuitable for mass-production of poled materials.

Thermal poling involves the heating of the entire bulk glass or optical fibre in an oven. However, this method has been typically limited to uniform poling. For non-uniform poling, periodic electrodes have to be deposited onto e.g. the bulk glass.

This has required the heating to be performed in a vacuum to prevent smearing between adjacent poling domains by reducing electrical conductivity in air between the electrodes. This results in a complex poling system and furthermore, the periodic poling design of e.g. poled gratings was limited by the photolithographic mask used for

the deposition of the electrodes. Furthermore, as the sign of the EO coefficient can only be changed by applying a poling voltage of different polarity, this is practically impossible with such a poling system, since at the high voltages required, shortening between adjacent electrodes would occur.

Summary of the invention

A first aspect of the present invention provides a method of thermally poling a silica-based waveguide, comprising the steps of:

- exposing a region of the waveguide to an electric field;

- directing a laser beam into the region which is exposed to the electric field;

- irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

The method may further comprise scanning the laser beam across the region to effect poling of the region.

The method may comprise varying the power density of the laser beam while scanning. Accordingly, a method of non-uniform thermal poling can be provided.

A direction of the electric field may be changed as the laser beam is scanned over the region. Accordingly, it can be possible to alternate the sign of the EO coefficient in non-uniform thermal poling.

Where the material comprises glass, the laser beam is preferably an infrared (IR) laser, for example a CO_2 laser.

Where the material is an optical fibre, wires may be inserted into tubular holes extending substantially parallel to a core of the optical fibre located between the tubular holes, and a differential voltage may be applied to

the wires to create the electric field. The core of the optical fibre may comprise a germanosilicate material co-doped with phosphorous.

A second aspect of the present invention provides an apparatus for thermally poling a silica-based waveguide, comprising:

- a means for exposing a region of the waveguide to an electric field;

- a means for directing a laser beam into the region which is exposed to the electric field;

- a means for irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- a means for scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

A third aspect of the present invention provides an optical device incorporating a silica-based waveguide when thermally poled by the above-described method.

Preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings.

<u>Brief Description of the Drawings</u>

Figure 1 shows a schematic drawing of an experimental set-up embodying the present invention.

Figure 2 shows a plot illustrating positive poling as a function of time embodying the present invention.

Figure 3 shows a plot illustrating negative poling as a function of time embodying the present invention.

<u>Detailed Description of the Preferred Embodiments</u>

In Figure 1, a Mach-Zehnder interferometer 10 was used for in situ measurement of the evolution of the EO coefficient in an optical fibre 12. The optical fibre 12 is a twin hole fibre with a germano silicate core codoped

with phosphorous. The hole diameter is 108 micrometer and the hole-to-hole spacing was 16 micrometer.

A translation stage 14 is used to scan a CO_2 laser beam from a CO_2 laser 18, using a mirror 20 to direct the laser beam 16 onto the fibre 12.

Aluminium wires 22, 24 were inserted via side entries (not shown) into each of the holes of the twin hole fibre 12 to provide electrodes for applying a poling voltage across the core of the optical fibre 12.

The wires 22, 24 were connected to a DC high voltage power supply 26. During the experiments, a poling voltage of 3.5 kW was applied.

A high voltage AC signal generator 28 is provided in series with the DC power supply 26. The high voltage AC signal generator 28 was utilised as a means to measure the EO coefficient of the core of the optical fibre 12 as follows.

Whilst the DC component of the high voltage acts as the poling voltage, the AC signal (8.5 kHz) can be used to effect refractive index changes in the core of the optical fibre due to the electro-optic effect. As the EO coefficient of the core of the optical fibre 12 changes, so does an AC component of the output of the Mach-Zehnder interferometer 10. The output of the Mach-Zehnder interferometer 10 is measured through a differential amplifier set-up 30 and analysed by a computer 32.

In the arm 34 of the Mach-Zehnder interferometer 10 which does not include the optical fibre 12 a linear ramp phase modulator 36 is used to get around thermal drift instabilities of the Mach-Zehnder interferometer during the experiment in a known manner.

The scan time for scanning the laser beam 16 along the approximately 7 cm of the optical fibre 12 was set at 55 seconds.

Turning now to Figure 2, a typical EO evolution achieved during exposure of the fibre 12 (Figure 1) with a

positive applied high voltage. During a first period 40 when the DC high voltage and the laser beam are turned off, no EO effect is observable, which is characteristic for glass, which does not exhibit a measurable EO coefficient.

When the poling voltage is applied in the next segment 42, the EO coefficient jumps to a positive value (44). In the next segment 46 the laser beam is unblocked and the scan begins (whilst the poling voltage remains applied), and the quantity (EO coefficient*length of scanned fibre) grows rapidly during of the plot. In other words, the cumulative electrooptic phase shift caused by the fibre increases as the length of poled fibre increases during the scan.

When the scan ends and the laser beam is blocked again, the EO coefficient stops growing and remains substantially constant during the next segment 48, whilst the DC poling voltage remains applied.

Finally, upon turning the poling voltage off, a residual EO coefficient 50 remains, in the case illustrated in Figure 2 the residual EO value 50 is approximately 2.03 pm/V.cm. At the end of the scan, the EO coefficient is the same at any point along the scanned region, i.e. 2.03 pm/V.cm divided by 7 cm (the scanned length) = 0.29 pm/V.

(We note that during the entire measurement of the plot illustrated in Figure 2, the AC signal remains being applied to measure the EO coefficient).

Turning now to Figure 3, negative poling will now be described.

Again, initially when the poling voltage and the laser beam are turned off, only a noise level is measured in the first segment 60 of the plot shown in Figure 3, as expected for glass.

In the next segment 62, when the DC poling voltage is turned on, the EO coefficient jumps to a substantially constant value 64, we note that the sign of the EO coefficient is opposite to the EO coefficients in Figure 2

due to a poling voltage of different polarity being applied during the negative poling experiment.

In the next segment 66 of the plot shown in Figure 3, the laser beam is unblocked and the scan begins, the quantity (EO coefficient*length of scanned fibre) decays but remains non-zero.

When the scan ends and the beam is blocked, the EO coefficient stops decaying and maintains substantially constant whilst the poling voltage is still applied during segment 68 of the plot shown in Figure 3.

Finally, when the poling voltage is turned off, a residual (negative) EO coefficient 70 remains, in this case -0.91 pm/V.cm.

<u>Applications</u>

Non-uniformly poled waveguides such as optical fibres can be used for the fabrication of quasi-phase-matched (QPM) optical devices. The phase matching condition can be satisfied by choosing the correct period for a periodic poled grating.

QPM can be realised in glass and optical fibres using the present invention by for example varying the polarity of the applied poling voltage between different regions that are being poled.

Quasi-Phase-Matched gratings can be used for optical frequency mixing and optical switches.

The efficiency of frequency conversion is dependent on the amplitude of the EO coefficient variations in the gratings over the poled length of a waveguide. This has limited the application of poled gratings for frequency conversion, since the EO coefficient variations are typically small, especially in thermal poling.

However, with the present invention, the efficiency of the frequency conversion can be increased because it is now possible to produce poled gratings that are for example metres long, thereby in its cumulative effect overcoming the deficiency problem.

With the method of the present invention, relatively high EO coefficients have been poled in relatively short times compared to thermal poling, which typically requires a time of 10 minutes at 280ºC with a 3.5 kV poling voltage to achieve EO coefficients of 0.15 to 0.2 pm/V, i.e. smaller than the EO coefficients achieved with the present invention within 55 seconds.

This can enable rapid poling of optical fibres for commercial manufacture, where for example the CO_2 laser is used to rapidly heat up silicate glass while a poling voltage is applied across the glass as described above.

Furthermore, if a twin-hole optic fibre with electrode wires already in the holes is drawn this enables poling of optical fibres either before or during the drawing of the fibre whilst applying a voltage across the two embedded electrode wires. This could allow very long lengths of poled optical fibre to be produced.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

The claims defining the invention are:

1. A method of thermally poling a silica-based waveguide, comprising the steps of:

- exposing a region of the waveguide to an electric field;

- directing a laser beam into the region which is exposed to the electric field;

- irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

2. A method as claimed in claim 1 wherein the laser is controlled to such that the power density of the laser beam is varied while scanning.

3. A method as claimed in any one of the preceding claims wherein a direction of the electric field is changed as the laser beam is scanned over the region.

4. A method as claimed in claim 3, wherein the direction of the electric field is reversed as the laser beam is scanned over the region.

5. A method as claimed in any one of the preceding claims wherein the electric field and/or laser are controlled to effect a non-uniformly poled structure in the region.

6. A method as claimed in claim 5 wherein the electric field and/or laser are controlled to effect a periodic poled structre.

7. A method as claimed in any one of the preceding claims wherein the laser beam is an IR laser beam.

8. A method as claimed in any one of the preceding claims when applied to a waveguide in the form of an optical fibre.

9. A method as claimed in claim 8, wherein wires are inserted into tubular holes extending substantially parallel to a core of the optical fibre located between the tubular holes, and a differential voltage is applied to the wires to create the electric field.

10. A method as claimed in either claim 8 or claim 9, when applied to an optical fibre in which the core comprises germanosilicate co-doped with phosphorous.

11. An apparatus for thermally poling a silica-based waveguide, comprising:

- a means for exposing a region of the waveguide to an electric field;
- a means for directing a laser beam into the region which is exposed to the electric field;
- a means for irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and
- a means for scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

12. An optical device incorporating a silica-based waveguide when thermally poled by the method as claimed in any one of claims 1 to 11.

13. A method of thermally poling a silica-based waveguide substantially as herein described with reference to the accompanying drawings.

14. An apparatus for thermally poling a silica-based waveguide substantially as herein described with reference to the accompanying drawings.

Dated this 14th day of September 2000
<u>The University of Sydney</u>
By their Patent Attorneys
GRIFFITH HACK

10/049334

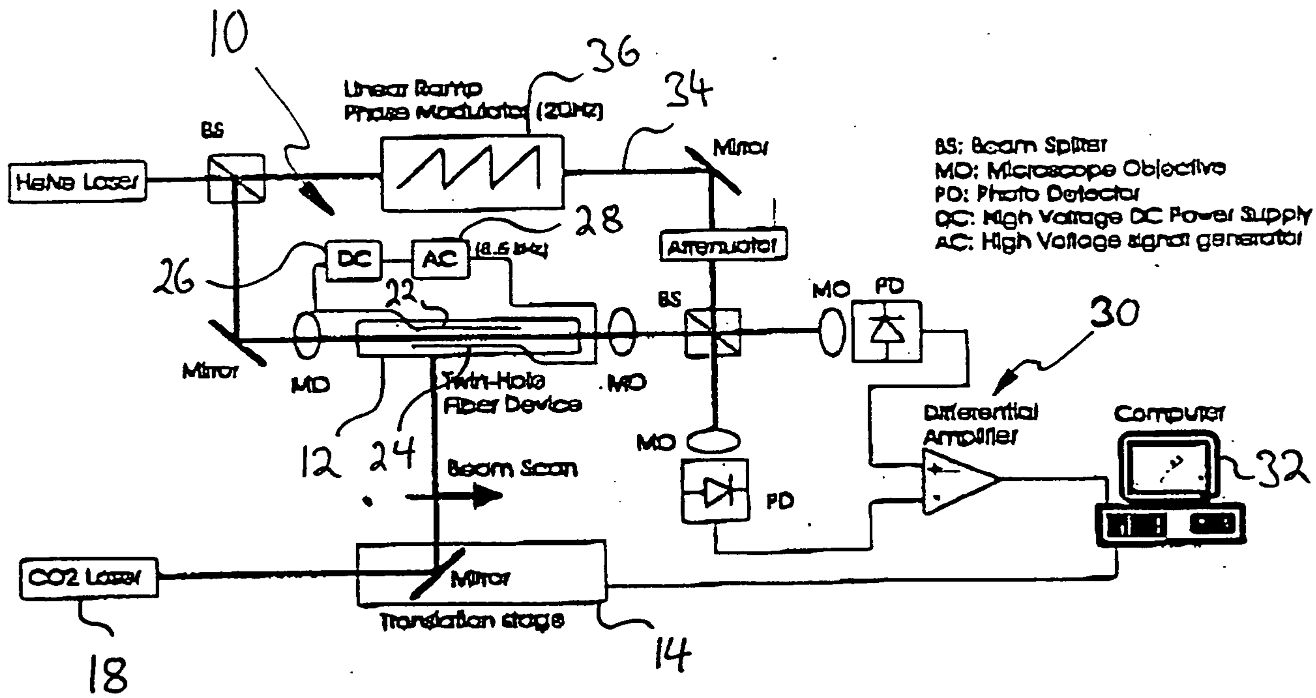


Figure 1

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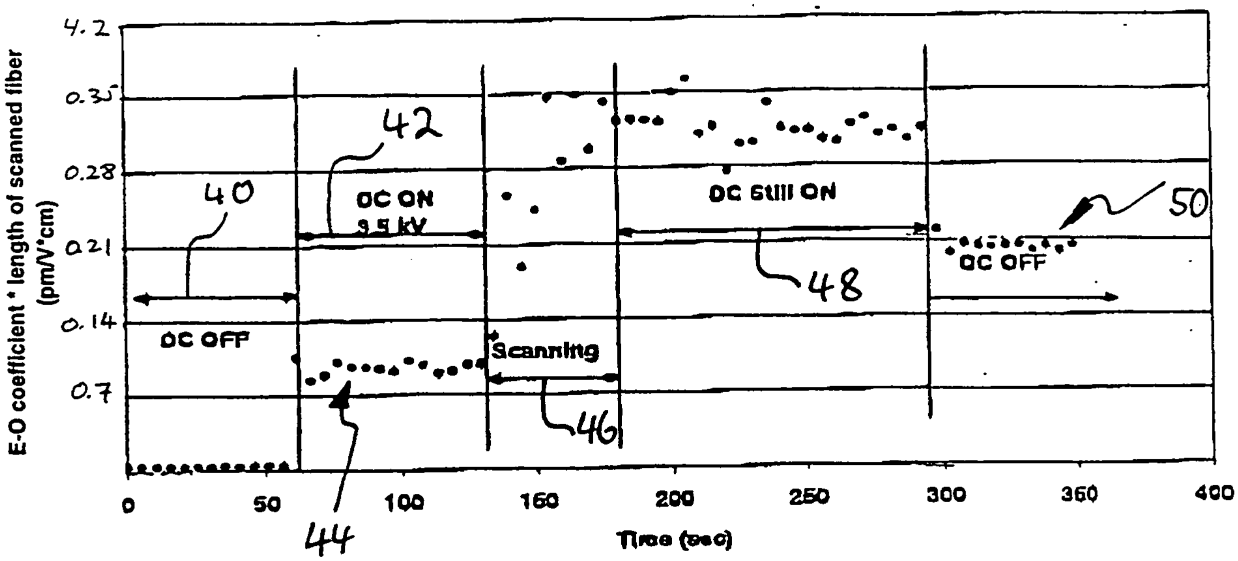

Figure 2

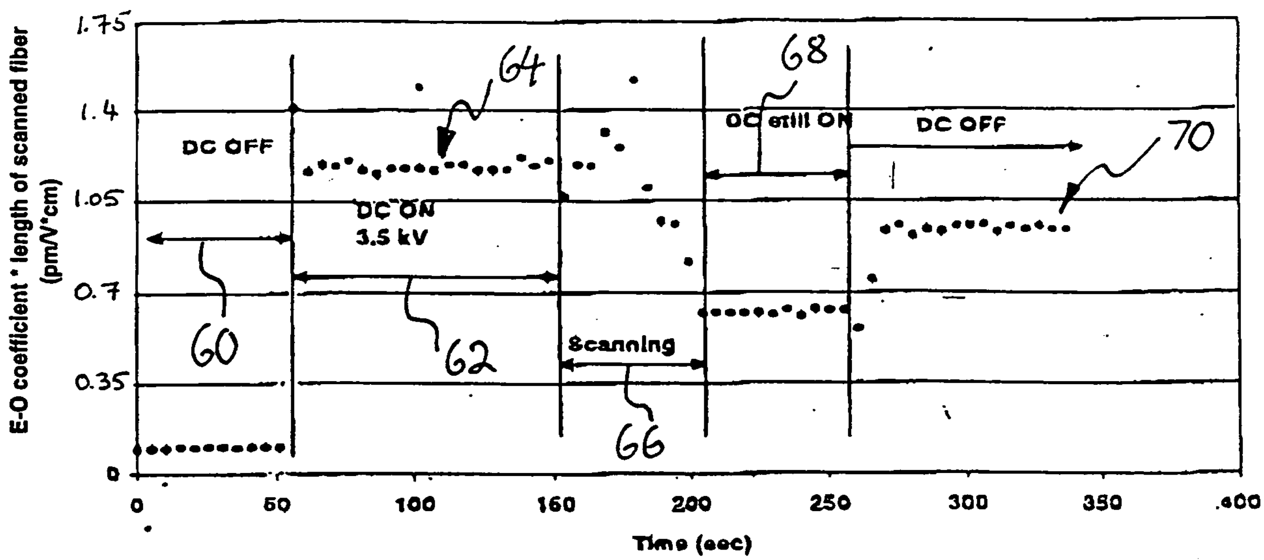
E-O coefficient * length of scanned fiber (pm/V*cm)
Time (sec)
DC OFF
DC ON
3.5 kV
Scanning
DC still ON
DC OFF
60
62
64
66
68
70
1.75
1.4
1.05
0.7
0.35
0
0
50
100
150
200
250
300
350
400

Figure 3

INTERNATIONAL SEARCH REPORT

International application No. PCT/AU00/01115

A.	CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: G02F 1/035, 1/383

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G02B, G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DWPI, JAPIO, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	Optics Letters, Vol 25, 15 February 2000 (Optical Society of America), "Carbon dioxide laser-assisted poling of silicate-based optical fibers ", P. Blazkiewicz et al., pp 200-202. Whole document	1-14
X Y	Optical Materials, Vol. 9, January 1998 (Elsevier Science B.V.), "Study of organized $\chi^{(2)}$ susceptibility in germanosilicate optical fibers", Y. Quiquempois et al., pp. 361-367. Sections 1-2, 4	1, 7-14 2-6

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 November 2000	15 NOV 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer MICHAEL HALL Telephone No : (02) 6283 2474

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	WO 96/16344 A (UNIVERSITY OF SYDNEY) 30 May 1996	
Y	Page 6 lines 29-31, pages 9-10	2-6
A	Whole document	1, 7-14
	US 5856880 A (FARINA ET AL.) 5 January 1999	
Y	Column 2 line 28 to column 3 line 8, column 12 lines 37-63	2-6
A	Whole document	1, 7-14

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/01115

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	9616344	AU	38646/95	CA	2206018	EP	792473
		US	5966233				
US	5856880	NONE					

END OF ANNEX

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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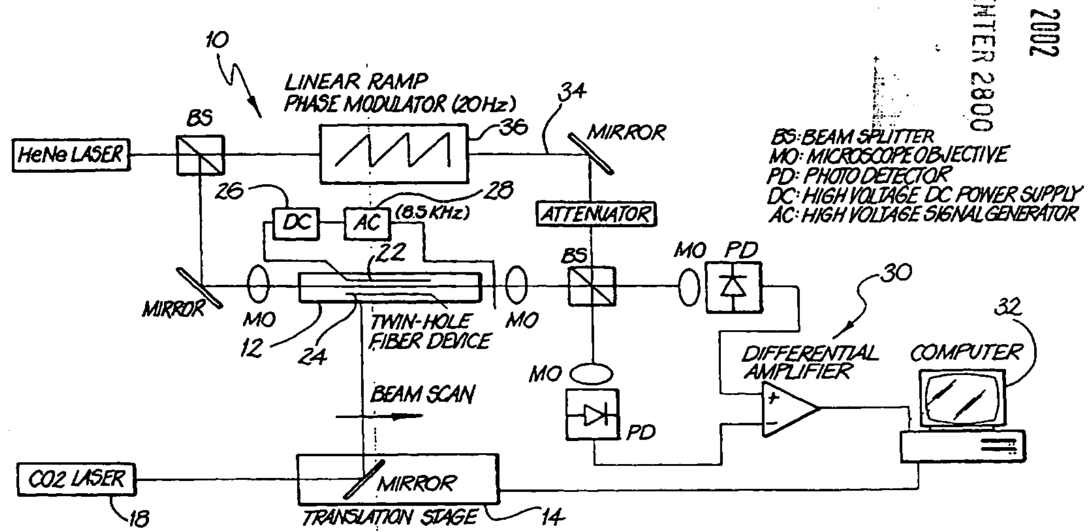
(54) Title: LASER ASSISTED THERMAL POLING OF SILICA BASED WAVEGUIDES



(57) Abstract: A method of thermally poling a silica based waveguide (12) comprises exposing a region of the waveguide (12) to an electric field (for example, via capillary electrodes (22, 24) inserted into holes in the waveguide); directing a laser beam (18) into the region exposed to the electric field to effect localised heating of the region via direct absorption; and scanning the laser beam (18) over the region at a rate selected to avoid heating of the region above the glass transition temperature. Reversing the electric field while scanning the laser beam (18) allows the formation of periodic poled gratings. The waveguide (12) can comprise an optical fibre.

WO 01/020389 A1

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LASER ASSISTED THERMAL POLING OF SILICA BASED WAVEGUIDES

Field of the invention

The present invention relates broadly to a method and apparatus for thermal poling of materials and to devices incorporating poled materials.

Background of the invention

The induced variation of the electro-optic (EO) coefficient of materials (hereinafter referred to as poling) has been attempted e.g. for optical fibres and bulk glass to produce a residual EO coefficient chi(2) in the glass material.

Two main methods are presently applied for poling optical fibres or bulk glass: (I) thermal poling and (II) ultraviolet (UV) poling. The latter is believed to effect poling through non-thermal effects caused by UV absorption in the glass.

In both methods, a high poling voltage is applied across the material during either the heating process or the UV absorption to produce the EO coefficient changes.

The largest values of the EO coefficient in glass have been produced by UV poling. However, the resulting EO variations have been difficult to reproduce and the underlying principles are not fully understood, which makes this method unsuitable for mass-production of poled materials.

Thermal poling involves the heating of the entire bulk glass or optical fibre in an oven. However, this method has been typically limited to uniform poling. For non-uniform poling, periodic electrodes have to be deposited onto e.g. the bulk glass.

This has required the heating to be performed in a vacuum to prevent smearing between adjacent poling domains by reducing electrical conductivity in air between the electrodes. This results in a complex poling system and furthermore, the periodic poling design of e.g. poled gratings was limited by the photolithographic mask used for

the deposition of the electrodes. Furthermore, as the sign of the EO coefficient can only be changed by applying a poling voltage of different polarity, this is practically impossible with such a poling system, since at the high voltages required, shortening between adjacent electrodes would occur.

Summary of the invention

A first aspect of the present invention provides a method of thermally poling a silica-based waveguide, comprising the steps of:

- exposing a region of the waveguide to an electric field;

- directing a laser beam into the region which is exposed to the electric field;

- irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

The method may further comprise scanning the laser beam across the region to effect poling of the region.

The method may comprise varying the power density of the laser beam while scanning. Accordingly, a method of non-uniform thermal poling can be provided.

A direction of the electric field may be changed as the laser beam is scanned over the region. Accordingly, it can be possible to alternate the sign of the EO coefficient in non-uniform thermal poling.

Where the material comprises glass, the laser beam is preferably an infrared (IR) laser, for example a CO_2 laser.

Where the material is an optical fibre, wires may be inserted into tubular holes extending substantially parallel to a core of the optical fibre located between the tubular holes, and a differential voltage may be applied to

the wires to create the electric field. The core of the optical fibre may comprise a germanosilicate material co-doped with phosphorous.

A second aspect of the present invention provides an apparatus for thermally poling a silica-based waveguide, comprising:

- a means for exposing a region of the waveguide to an electric field;
- a means for directing a laser beam into the region which is exposed to the electric field;
- a means for irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and
- a means for scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

A third aspect of the present invention provides an optical device incorporating a silica-based waveguide when thermally poled by the above-described method.

Preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 shows a schematic drawing of an experimental set-up embodying the present invention.

Figure 2 shows a plot illustrating positive poling as a function of time embodying the present invention.

Figure 3 shows a plot illustrating negative poling as a function of time embodying the present invention.

Detailed Description of the Preferred Embodiments

In Figure 1, a Mach-Zehnder interferometer 10 was used for in situ measurement of the evolution of the EO coefficient in an optical fibre 12. The optical fibre 12 is a twin hole fibre with a germano silicate core codoped

with phosphorous. The hole diameter is 108 micrometer and the hole-to-hole spacing was 16 micrometer.

A translation stage 14 is used to scan a CO_2 laser beam from a CO_2 laser 18, using a mirror 20 to direct the laser beam 16 onto the fibre 12.

Aluminium wires 22, 24 were inserted via side entries (not shown) into each of the holes of the twin hole fibre 12 to provide electrodes for applying a poling voltage across the core of the optical fibre 12.

The wires 22, 24 were connected to a DC high voltage power supply 26. During the experiments, a poling voltage of 3.5 kW was applied.

A high voltage AC signal generator 28 is provided in series with the DC power supply 26. The high voltage AC signal generator 28 was utilised as a means to measure the EO coefficient of the core of the optical fibre 12 as follows.

Whilst the DC component of the high voltage acts as the poling voltage, the AC signal (8.5 kHz) can be used to effect refractive index changes in the core of the optical fibre due to the electro-optic effect. As the EO coefficient of the core of the optical fibre 12 changes, so does an AC component of the output of the Mach-Zehnder interferometer 10. The output of the Mach-Zehnder interferometer 10 is measured through a differential amplifier set-up 30 and analysed by a computer 32.

In the arm 34 of the Mach-Zehnder interferometer 10 which does not include the optical fibre 12 a linear ramp phase modulator 36 is used to get around thermal drift instabilities of the Mach-Zehnder interferometer during the experiment in a known manner.

The scan time for scanning the laser beam 16 along the approximately 7 cm of the optical fibre 12 was set at 55 seconds.

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positive applied high voltage. During a first period 40 when the DC high voltage and the laser beam are turned off, no EO effect is observable, which is characteristic for glass, which does not exhibit a measurable EO coefficient.

When the poling voltage is applied in the next segment 42, the EO coefficient jumps to a positive value (44). In the next segment 46 the laser beam is unblocked and the scan begins (whilst the poling voltage remains applied), and the quantity (EO coefficient*length of scanned fibre) grows rapidly during of the plot. In other words, the cumulative electrooptic phase shift caused by the fibre increases as the length of poled fibre increases during the scan.

When the scan ends and the laser beam is blocked again, the EO coefficient stops growing and remains substantially constant during the next segment 48, whilst the DC poling voltage remains applied.

Finally, upon turning the poling voltage off, a residual EO coefficient 50 remains, in the case illustrated in Figure 2 the residual EO value 50 is approximately 2.03 pm/V.cm. At the end of the scan, the EO coefficient is the same at any point along the scanned region, i.e. 2.03 pm/V.cm divided by 7 cm (the scanned length) = 0.29 pm/V.

(We note that during the entire measurement of the plot illustrated in Figure 2, the AC signal remains being applied to measure the EO coefficient).

Turning now to Figure 3, negative poling will now be described.

Again, initially when the poling voltage and the laser beam are turned off, only a noise level is measured in the first segment 60 of the plot shown in Figure 3, as expected for glass.

In the next segment 62, when the DC poling voltage is turned on, the EO coefficient jumps to a substantially constant value 64, we note that the sign of the EO coefficient is opposite to the EO coefficients in Figure 2

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Finally, when the poling voltage is turned off, a residual (negative) EO coefficient 70 remains, in this case -0.91 pm/V.cm.

Applications

Non-uniformly poled waveguides such as optical fibres can be used for the fabrication of quasi-phase-matched (QPM) optical devices. The phase matching condition can be satisfied by choosing the correct period for a periodic poled grating.

QPM can be realised in glass and optical fibres using the present invention by for example varying the polarity of the applied poling voltage between different regions that are being poled.

Quasi-Phase-Matched gratings can be used for optical frequency mixing and optical switches.

The efficiency of frequency conversion is dependent on the amplitude of the EO coefficient variations in the gratings over the poled length of a waveguide. This has limited the application of poled gratings for frequency conversion, since the EO coefficient variations are typically small, especially in thermal poling.

However, with the present invention, the efficiency of the frequency conversion can be increased because it is now possible to produce poled gratings that are for example metres long, thereby in its cumulative effect overcoming the deficiency problem.

With the method of the present invention, relatively high EO coefficients have been poled in relatively short times compared to thermal poling, which typically requires a time of 10 minutes at 280ºC with a 3.5 kV poling voltage to achieve EO coefficients of 0.15 to 0.2 pm/V, i.e. smaller than the EO coefficients achieved with the present invention within 55 seconds.

This can enable rapid poling of optical fibres for commercial manufacture, where for example the CO_2 laser is used to rapidly heat up silicate glass while a poling voltage is applied across the glass as described above.

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- directing a laser beam into the region which is exposed to the electric field;

- irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

2. A method as claimed in claim 1 wherein the laser is controlled to such that the power density of the laser beam is varied while scanning.

3. A method as claimed in any one of the preceding claims wherein a direction of the electric field is changed as the laser beam is scanned over the region.

4. A method as claimed in claim 3, wherein the direction of the electric field is reversed as the laser beam is scanned over the region.

5. A method as claimed in any one of the preceding claims wherein the electric field and/or laser are controlled to effect a non-uniformly poled structure in the region.

6. A method as claimed in claim 5 wherein the electric field and/or laser are controlled to effect a periodic poled structre.

7. A method as claimed in any one of the preceding claims wherein the laser beam is an IR laser beam.

8. A method as claimed in any one of the preceding claims when applied to a waveguide in the form of an optical fibre.

9. A method as claimed in claim 8, wherein wires are inserted into tubular holes extending substantially parallel to a core of the optical fibre located between the tubular holes, and a differential voltage is applied to the wires to create the electric field.

10. A method as claimed in either claim 8 or claim 9, when applied to an optical fibre in which the core comprises germanosilicate co-doped with phosphorous.

11. An apparatus for thermally poling a silica-based waveguide, comprising:

- a means for exposing a region of the waveguide to an electric field;
- a means for directing a laser beam into the region which is exposed to the electric field;
- a means for irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and
- a means for scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

12. An optical device incorporating a silica-based waveguide when thermally poled by the method as claimed in any one of claims 1 to 11.

13. A method of thermally poling a silica-based waveguide substantially as herein described with reference to the accompanying drawings.

14. An apparatus for thermally poling a silica-based waveguide substantially as herein described with reference to the accompanying drawings.

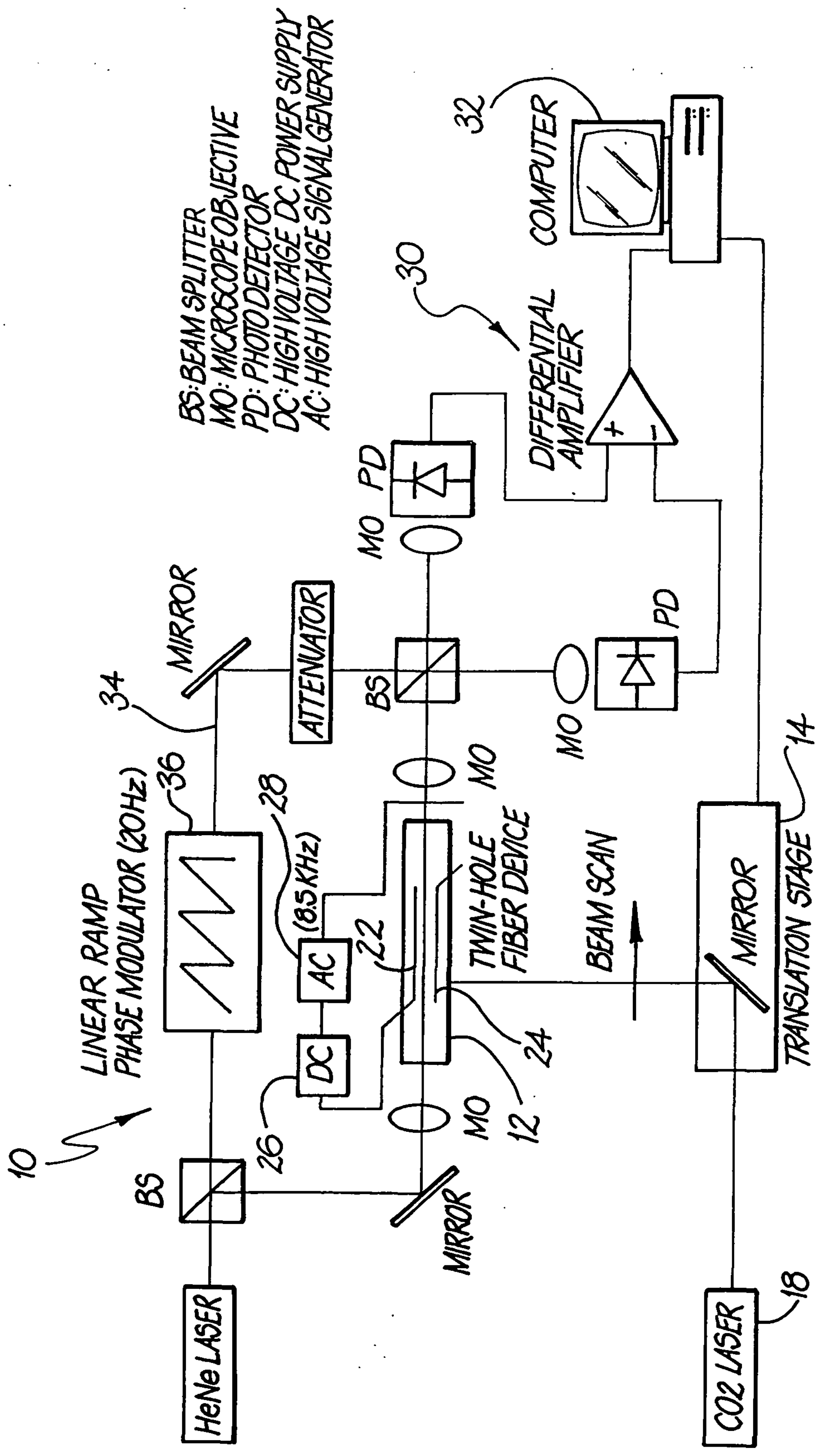
BS: BEAM SPLITTER
MO: MICROSCOPE OBJECTIVE
PD: PHOTO DETECTOR
DC: HIGH VOLTAGE DC POWER SUPPLY
AC: HIGH VOLTAGE SIGNAL GENERATOR
10
LINEAR RAMP PHASE MODULATOR (20Hz)
36
34
MIRROR
ATTENUATOR
BS
MO
PD
30
DIFFERENTIAL AMPLIFIER
+
-
32
COMPUTER
HeNe LASER
BS
MIRROR
26
DC
AC
28
(8.5 KHz)
22
24
12
MO
MO
TWIN-HOLE FIBER DEVICE
BEAM SCAN
MIRROR
TRANSLATION STAGE
14
CO2 LASER
18

FIG. 1

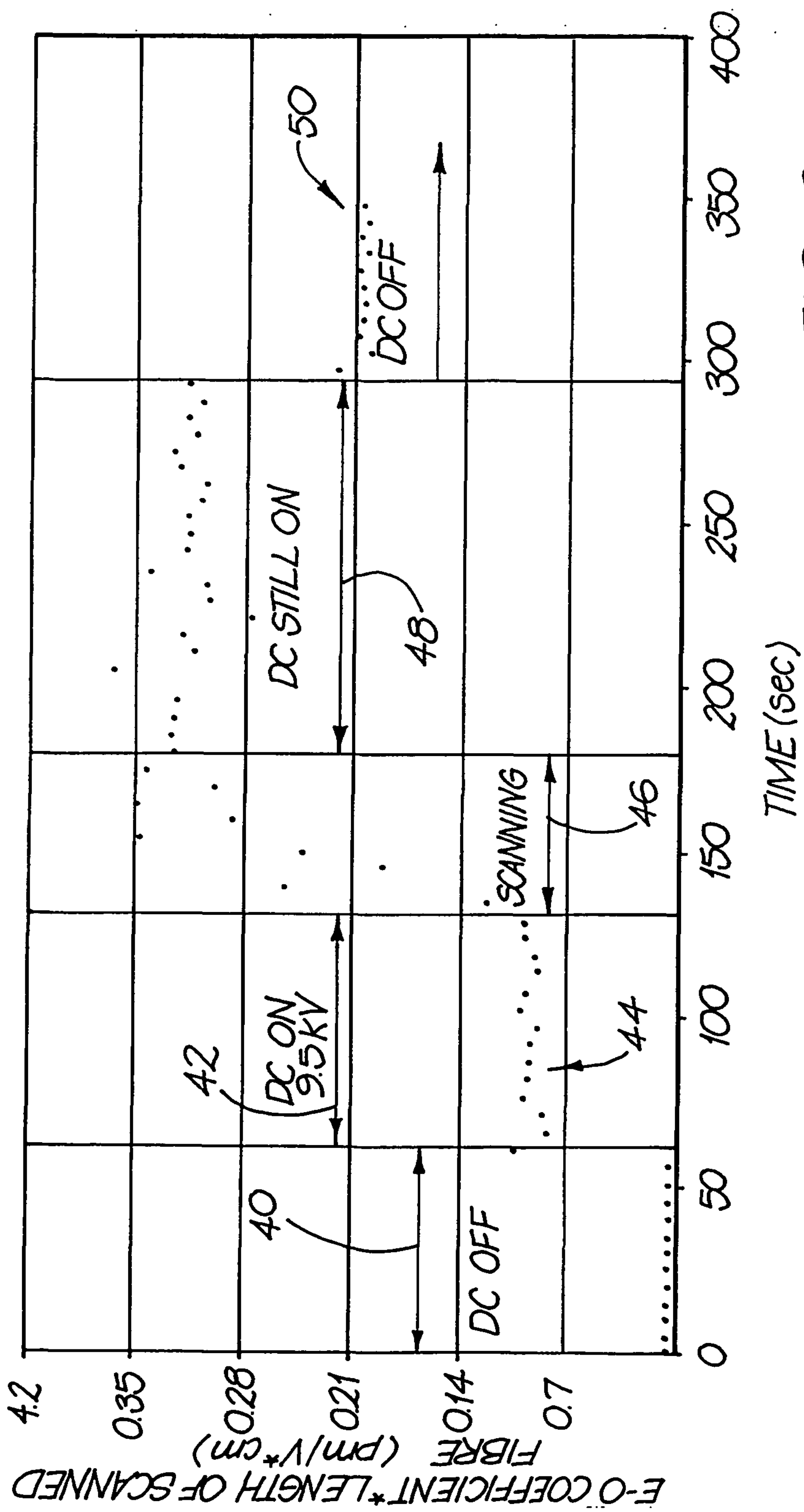
E-O COEFFICIENT*LENGTH OF SCANNED FIBRE (pm/V*cm)
4.2
0.35
0.28
0.21
0.14
0.7
TIME (sec)
0
50
100
150
200
250
300
350
400
DC OFF
40
DC ON 9.5KV
42
44
SCANNING
46
DC STILL ON
48
DC OFF
50

FIG. 2

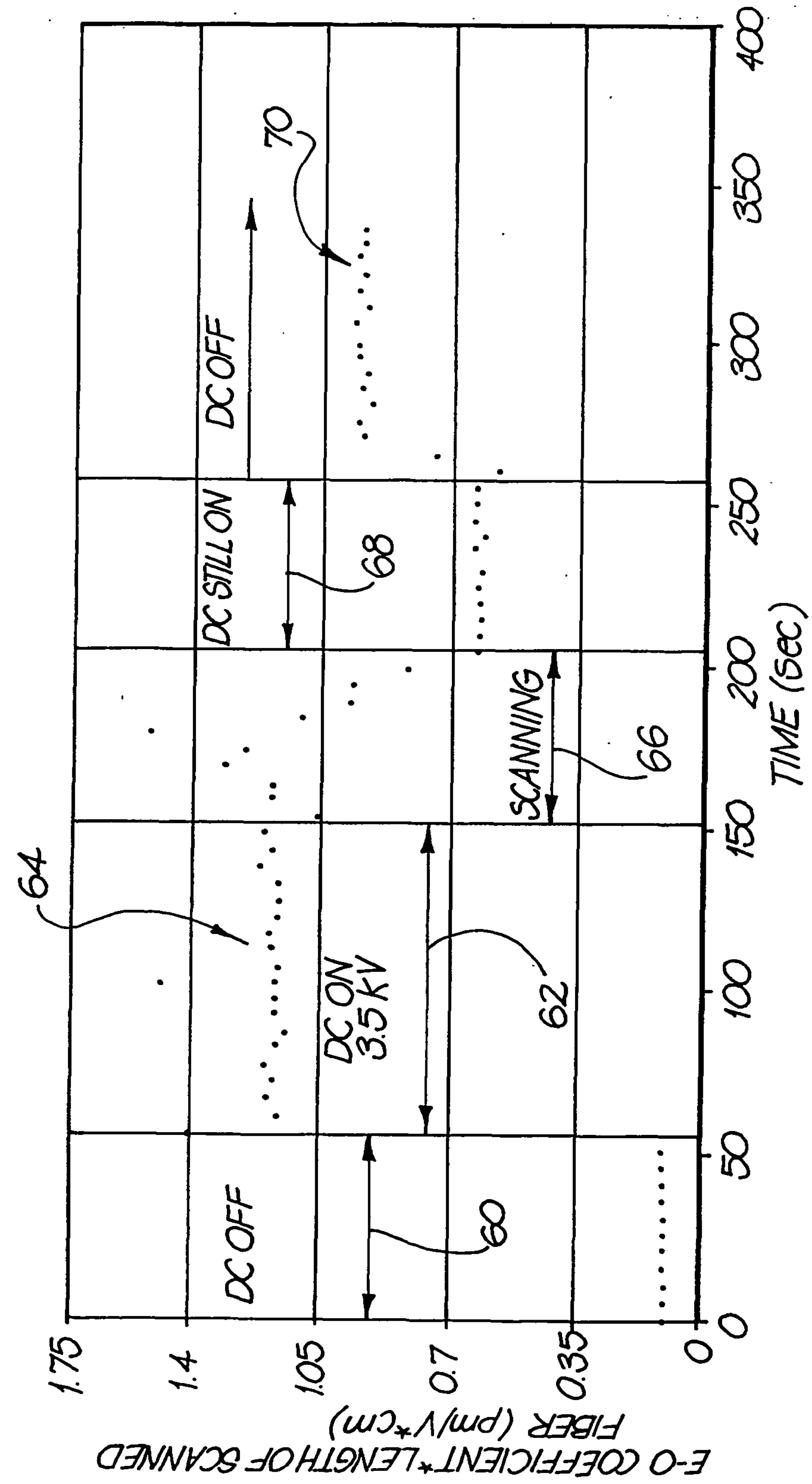
DC OFF
DC ON
3.5 kV
SCANNING
DC STILL ON
DC OFF
60
62
64
66
68
70
0
50
100
150
200
250
300
350
400
TIME (Sec)
0
0.35
0.7
1.05
1.4
1.75
E-O COEFFICIENT*LENGTH OF SCANNED FIBER (pm/V*cm)

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/01115

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: G02F 1/035, 1/383

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G02B, G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DWPI, JAPIO, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	Optics Letters, Vol 25, 15 February 2000 (Optical Society of America), "Carbon dioxide laser-assisted poling of silicate-based optical fibers ", P. Blazkiewicz et al., pp 200-202. Whole document	1-14
X Y	Optical Materials, Vol. 9, January 1998 (Elsevier Science B.V.), "Study of organized $\chi^{(2)}$ susceptibility in germanosilicate optical fibers", Y. Quiquempois et al., pp. 361-367. Sections 1-2, 4	1, 7-14 2-6

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 November 2000	15 NOV 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer MICHAEL HALL Telephone No : (02) 6283 2474

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	WO 96/16344 A (UNIVERSITY OF SYDNEY) 30 May 1996	
Y	Page 6 lines 29-31, pages 9-10	2-6
A	Whole document	1, 7-14
	US 5856880 A (FARINA ET AL.) 5 January 1999	
Y	Column 2 line 28 to column 3 line 8, column 12 lines 37-63	2-6
A	Whole document	1, 7-14

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/01115

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	9616344	AU	38646/95	CA	2206018	EP	792473
		US	5966233				
US	5856880	NONE					

END OF ANNEX

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/01115

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: G02F 1/035, 1/383

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G02B, G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DWPI, JAPIO, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	Optics Letters, Vol 25, 15 February 2000 (Optical Society of America), "Carbon dioxide laser-assisted poling of silicate-based optical fibers ", P. Blazkiewicz et al., pp 200-202. Whole document	1-14
X Y	Optical Materials, Vol. 9, January 1998 (Elsevier Science B.V.), "Study of organized $\chi^{(2)}$ susceptibility in germanosilicate optical fibers", Y. Quiquempois et al., pp. 361-367. Sections 1-2, 4	1, 7-14 2-6

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search	Date of mailing of the international search report
8 November 2000	15 NOV 2000
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer MICHAEL HALL Telephone No : (02) 6283 2474

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	WO 96/16344 A (UNIVERSITY OF SYDNEY) 30 May 1996	
Y	Page 6 lines 29-31, pages 9-10	2-6
A	Whole document	1, 7-14
	US 5856880 A (FARINA ET AL.) 5 January 1999	
Y	Column 2 line 28 to column 3 line 8, column 12 lines 37-63	2-6
A	Whole document	1, 7-14

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/01115

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	9616344	AU	38646/95	CA	2206018	EP	792473
		US	5966233				
US	5856880	NONE					

END OF ANNEX

REPLACED BY ART 34 AMDT

the deposition of the electrodes. Furthermore, as the sign of the EO coefficient can only be changed by applying a poling voltage of different polarity, this is practically impossible with such a poling system, since at the high voltages required, shortening between adjacent electrodes would occur.

Summary of the invention

A first aspect of the present invention provides a method of thermally poling a silica-based waveguide, comprising the steps of:

- exposing a region of the waveguide to an electric field;
- directing a laser beam into the region which is exposed to the electric field;
- irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and
- scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

The method may further comprise scanning the laser beam across the region to effect poling of the region.

The method may comprise varying the power density of the laser beam while scanning. Accordingly, a method of non-uniform thermal poling can be provided.

A direction of the electric field may be changed as the laser beam is scanned over the region. Accordingly, it can be possible to alternate the sign of the EO coefficient in non-uniform thermal poling.

Where the material comprises glass, the laser beam is preferably an infrared (IR) laser, for example a CO_2 laser.

Where the material is an optical fibre, wires may be inserted into tubular holes extending substantially parallel to a core of the optical fibre located between the tubular holes, and a differential voltage may be applied to

the wires to create the electric field. The core of the optical fibre may comprise a germanosilicate material co-doped with phosphorous.

A second aspect of the present invention provides an apparatus for thermally poling a silica-based waveguide, comprising:

- a means for exposing a region of the waveguide to an electric field;

- a means for directing a laser beam into the region which is exposed to the electric field;

- a means for irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- a means for scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

A third aspect of the present invention provides an optical device incorporating a silica-based waveguide when thermally poled by the above-described method.

Preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 shows a schematic drawing of an experimental set-up embodying the present invention.

Figure 2 shows a plot illustrating positive poling as a function of time embodying the present invention.

Figure 3 shows a plot illustrating negative poling as a function of time embodying the present invention.

Detailed Description of the Preferred Embodiments

In Figure 1, a Mach-Zehnder interferometer 10 was used for in situ measurement of the evolution of the EO coefficient in an optical fibre 12. The optical fibre 12 is a twin hole fibre with a germano silicate core codoped

The claims defining the invention are:

1. A method of thermally poling a silica-based waveguide, comprising the steps of:

- exposing a region of the waveguide to an electric field;

- directing a laser beam into the region which is exposed to the electric field;

- irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

2. A method as claimed in claim 1 wherein the laser is controlled to such that the power density of the laser beam is varied while scanning.

3. A method as claimed in any one of the preceding claims wherein a direction of the electric field is changed as the laser beam is scanned over the region.

4. A method as claimed in claim 3, wherein the direction of the electric field is reversed as the laser beam is scanned over the region.

5. A method as claimed in any one of the preceding claims wherein the electric field and/or laser are controlled to effect a non-uniformly poled structure in the region.

6. A method as claimed in claim 5 wherein the electric field and/or laser are controlled to effect a periodic poled structre.

7. A method as claimed in any one of the preceding claims wherein the laser beam is an IR laser beam.

8. A method as claimed in any one of the preceding claims when applied to a waveguide in the form of an optical fibre.

9. A method as claimed in claim 8, wherein wires are inserted into tubular holes extending substantially parallel to a core of the optical fibre located between the tubular holes, and a differential voltage is applied to the wires to create the electric field.

10. A method as claimed in either claim 8 or claim 9, when applied to an optical fibre in which the core comprises germanosilicate co-doped with phosphorous.

11. An apparatus for thermally poling a silica-based waveguide, comprising:

- a means for exposing a region of the waveguide to an electric field;

- a means for directing a laser beam into the region which is exposed to the electric field;

- a means for irradiating the region at a power density selected to effect localised heating of the waveguide within the region through direct absorption of the laser radiation; and

- a means for scanning the laser beam over the region at a rate selected to avoid heating of the region above a glass transition temperature of the region.

12. An optical device incorporating a silica-based waveguide when thermally poled by the method as claimed in any one of claims 1 to 11.

13. A method of thermally poling a silica-based waveguide substantially as herein described with reference to the accompanying drawings.

14. An apparatus for thermally poling a silica-based waveguide substantially as herein described with reference to the accompanying drawings.

Dated this 14th day of September 2000

The University of Sydney

By their Patent Attorneys

GRIFFITH HACK

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference AJM:MG:FP12950	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. **PCT/AU00/01115**	International Filing Date *(day/month/year)* 14 September 2000	Priority Date *(day/month/year)* 14 September 1999

International Patent Classification (IPC) or national classification and IPC

Int. Cl. 7 G02F 1/035, 1/383

Applicant

THE UNIVERSITY OF SYDNEY et al

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

   [X] This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 4 sheet(s).

3. This report contains indications relating to the following items:

I	[X]	Basis of the report
II	[ ]	Priority
III	[ ]	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
IV	[ ]	Lack of unity of invention
V	[X]	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
VI	[ ]	Certain documents cited
VII	[X]	Certain defects in the international application
VIII	[ ]	Certain observations on the international application

Date of submission of the demand 22 March 2001	Date of completion of the report 7 September 2001
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer **MICHAEL HALL** Telephone No. (02) 6283 2474

I. Basis of the report

1. With regard to the **elements** of the international application:*

[ ] the international application as originally filed.

[X] the description, pages **1, 4-7,** as originally filed,
pages , filed with the demand,
pages **2-3,** received on **23 August 2001** with the letter of **23 August 2001**

[X] the claims, pages , as originally filed,
pages , as amended (together with any statement) under Article 19,
pages , filed with the demand,
pages **8-9,** received on **23 August 2001** with the letter of **23 August 2001**

[X] the drawings, pages **1-3,** as originally filed,
pages , filed with the demand,
pages , received on with the letter of

[ ] the sequence listing part of the description:
pages , as originally filed
pages , filed with the demand
pages , received on with the letter of

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language which is:

[ ] the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

[ ] the language of publication of the international application (under Rule 48.3(b)).

[ ] the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readable form.

[ ] The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

4. [ ] The amendments have resulted in the cancellation of:

[ ] the description, pages

[ ] the claims, Nos.

[ ] the drawings, sheets/fig.

5. [ ] This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report*

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	**1-14**	**YES**
	Claims		**NO**
Inventive step (IS)	Claims	**1-14**	**YES**
	Claims		**NO**
Industrial applicability (IA)	Claims	**1-14**	**YES**
	Claims		**NO**

2. Citations and explanations (Rule 70.7)

Citation

D1 : Y. Quiquempois et al., Optical Materials 9 (1998) 361-367

NOVELTY (N) AND INVENTIVE STEP (IS)

D1 represents the closest prior art, and teaches thermally poling an optical fibre by applying an electric field to conductors inserted in the fibre, and exposing the region to be poled to a CO_2-laser beam to effect localised heating of the region between room temperature and 800 degrees Celsius. In an embodiment D1 teaches heating a 4mm length of fibre to 400 degrees Celsius for one hour (page 366, column 1).

However, D1 does not disclose or suggest scanning the laser beam over the region, as per the claims. Since this appears to lead to significantly improved poling properties (eg, 0.06 pm/V at page 366 column 1 of D1, compared to 0.29 pm/V at page 5 of the instant application), in significantly shorter times (eg, 1 hour at page 366 column 1 of D1, compared to 55 seconds at page 7 of the instant application), the claims are considered to be novel and inventive over D1.

INDUSTRIAL APPLICABILITY (IA)

The subject matter of the claims is applicable to the industrial manufacture of poled optical waveguide devices.

VII.	**Certain defects in the international application**

The following defects in the form or contents of the international application have been noted:

Claims 13 and 14 rely on reference to the drawings, and hence do not comply with PCT Rule 6.2(a).